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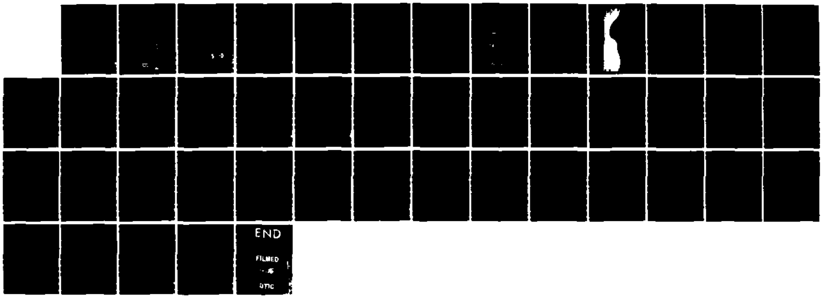

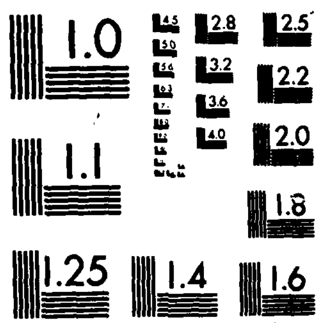

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Final Report

OFFICE OF NAVAL RESEARCH

For Contract N00014-76-C-0207 on

GEOMAGNETIC DISTURBANCES

For the Period
September 1, 1975 to September 30, 1985

January 1986

CENTER FOR SPACE SCIENCE AND ASTROPHYSICS
STANFORD UNIVERSITY
Stanford, California

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Submitted by:

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Foreword

This is the final report for research on the origins of "Geomagnetic Disturbances" supported under The Office of Naval Research, Contract N00014-76-C-0207, project NR 323-003, under the direction of Dr. Philip H. Scherrer as Principal Investigator and Professor Peter A. Sturrock as a co-investigator. The research has been carried out at the Wilcox Solar Observatory at Stanford University, Stanford, California.

Final Report of Naval Research

Contract N00014-76-C-0207

Project NR 323-003

GEOMAGNETIC DISTURBANCES

This is the final report on research on the causes of "Geomagnetic Disturbances". The project began in 1976 under the direction of Professor (Research) John M. Wilcox as Principal Investigator with the collaboration of Dr. Philip Scherrer. After the death of Prof. Wilcox in 1983, the work continued under the direction of Dr. Scherrer with Prof. Peter A. Sturrock as Principal Investigator. In 1985 Dr. Scherrer became Principal Investigator. The work has been done at Stanford University first in the Institute for Plasma research, then in 1983 in the Center for Space Science and Astrophysics.

Our investigations have included observations and analysis of the solar and interplanetary quantities relevant to geomagnetic activity. The operation of the John M. Wilcox Solar Observatory (formerly the Stanford Solar Observatory) and analysis of the synoptic observations of magnetic fields has constituted a significant part of the effort.

This report will detail our progress in the last year of the contract. Previous years results have been described in the yearly proposals for continued support. the emphasis of the research during the past few years has been to attempt to understand the timing and severity of geomagnetic disturbances by understanding the solar mechanisms responsible for the origin of solar wind variations.

Recent efforts have been concentrated in several areas of research. These include the study of the solar dynamics by directly observing the surface manifestations of giant scale convective motions. A knowledge of the structure of the convection zone is crucial to the eventual understanding of the solar magnetic cycle. We are also continued our study of the origin and structure of coronal magnetic fields and the origin of solar wind variability. The "static" structure of the corona is governed by the large scale organization of photospheric fields. During times of low activity, these fields can be used to infer the coronal structure with reasonable accuracy. Our synoptic series of high accuracy low resolution magnetic observations continues to provide a useful source for a number of investigations conducted at Stanford and elsewhere. We also investigated the relation between the effects of transient events and the large scale ambient structure. ~~We found that~~ flare accelerated material that does not cross the heliospheric current sheet has a larger impact on the terrestrial environment than material from flares that must cross the current sheet to arrive at the earth.

Our recent progress in each of these areas will be discussed below.

Observations of Large Scale Solar Velocity Fields

Large scale horizontal flows on the sun have long been predicted by theory and are generally believed to exist in the convection zone but have not been previously observed. Such flows must be intimately connected with the generation and evolution of solar activity and the eventual understanding of solar magnetic field generation depends on an understanding of the flows.

One of the important goals of the Wilcox Observatory has been the observation of large scale velocity structures. The synoptic series of velocity observations was begun in 1976. This series of observations has been examined for the signature of large scale convective motions. The observations are low-resolution full-disk daily velocity maps. Clear wave patterns with amplitudes of 10 to 20 m/s have been found at low and mid latitudes. These patterns can be seen to move across the disk with solar rotation. They have a large latitudinal extent, sometimes crossing the equator, but are not generaly aligned on meridians. There are from 2 to 6 wave patterns around the sun at different times.

Recent analyses of similar observations made at Mt. Wilson Observatory have shown that there are no long lived convective rolls detectable in the photosphere at the 1 or 2 m/s level. These analyses were designed specifically to find convective rolls extending over a large range in latitude and with 10 to 40 waves around the sun [1]. The present analysis of Stanford observations finds horizontal flow patterns which are larger in scale, shorter in lifetime, and different in structure than those searched for in the Mt. Wilson studies.

Our analysis has proceeded by first removing static velocity patterns and the "limb effect" from the raw data by subtracting 54-day running means of each observing grid point. Previous analyses removed rotation and the limb shift by subtracting daily full disk fits. We have found that that procedure can contaminate the east-west component with noise from the red-shift associated with active regions. We then use all observations of each heliographic location to find the separate components of the velocity vector. Figure 1 shows a typical synoptic map of east-west motion. The light shaded areas show westward motion (faster than rotation), the dark shading corresponds to eastward motion (slower than rotation). The typical magnitude of the flows is 10 m/s. There is a possibility that this signal is contaminated by the redshifts present in magnetic regions. Tests with artificial redshifts do show east-west motions as artifacts, in with the opposite direction with less than a tenth the magnitude of the observed signal. Also, the observed signal and structure does not change much as the magnetic cycle progresses from maximum activity in 1979 and 1980 to low activity in 1984. This research is being pursued primarily by Scherrer and Richard Bogart in collaboration with Hirokazu Yoshimura of the University of Tokyo and was recently presented at the AAS meeting [2]. A paper describing the first results of this investigation is in final preparation.

Synoptic Observations of Solar Magnetic Fields

The observation, analysis, and interpretation of large scale magnetic field configurations continues to be a major part of our research. The analysis of this data was central to the work completed by Todd Hoeksema for his Ph.D. dissertation last year. In that work he raised a number of questions that are now being examined.

One of these concerns the evolution of the solar fields when viewed as a decomposition into several spherical harmonic coefficients. A study of evolution of the relative power in the various harmonic coefficients which describe the solar field has been completed. He has shown that while a simple tilted dipole description of the large scale solar and interplanetary field may be mathematically correct during some parts of the solar cycle, the polar field and the lower latitude fields that contribute to the lowest few multipole components evolve independently. A paper describing these results was presented at the Fourth European Solar Physics Colloquium [3] with a summary included here as Appendix A.

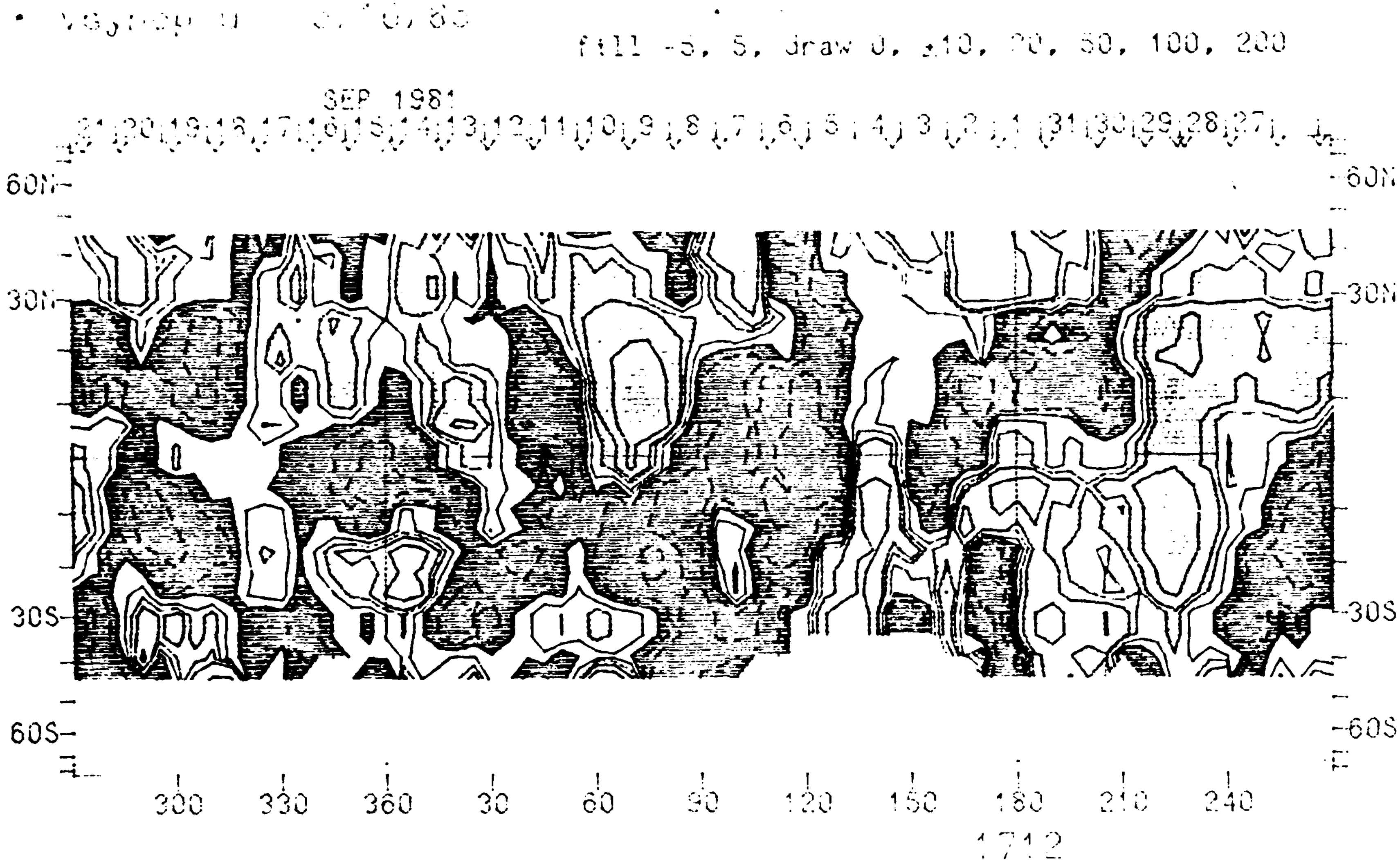

Figure 1. A map of east-west velocity on the sun for part of Carrington rotations 1712 and 1713. The dark shaded regions are moving eastward and the light shaded regions are moving westward. At equatorial and mid-latitudes there are 4 to 6 alternations of east and west motion around the sun. The typical amplitude is 10 m/s.

In order to make the surface field observations and the computed source surface coronal fields more readily available for comparative studies, we have prepared an atlas of solar fields for Carrington rotations 1641 through 1756. This atlas is presently being printed and will be made available to interested parties. Figure 2 is a representative page showing the computed field at the base of the solar wind. The positive fields are shown in light shading and the negative fields in dark shading. The surface fields will be shown in a format similar to that published monthly in Solar Geophysical Data by the World Data Center in Boulder.

In addition to our own analysis of our observations, we have encouraged collaborations in the analysis and application of the synoptic data obtained at Stanford. The Stanford synoptic data in the form prepared by Hoeksema has been useful for several such collaborative efforts. One project proceeding in collaboration with Steve Suess at MSFC involves modeling the expansion of the solar wind using the observed magnetic configuration. Another related project (with S. I. Akasofu of the University of Alaska) is using the Stanford observations as input to a kinematic model of solar wind expansion. We are also presently collaborating with K. W. Behannon who is comparing our predictions with spacecraft observations and with M. Stix (Kiepenheuer Institute) for studies of the solar internal field structure. The Stanford observations are also routinely used for forecasting interplanetary conditions at the NOAA Space Environment Laboratory (our data is sent to Boulder daily by a direct computer connection).

Solar Flare Acceleration of Solar Wind

The first stage of our investigation of the relation between the solar wind response to a solar flare and the location of the flare with respect to the large scale magnetic structure has been completed. A detailed analysis has been accepted for publication [4] and has been included here as Appendix B.

In the analysis, we used all flares in the Comprehensive Flare Index (CFI) compiled by Dodson and Hedeman [5] for which both solar wind velocity and Stanford magnetogram observations were available. Only flares with a CFI of 7 or greater were used. We divided the flares into two groups. In one group were all flares located on the same side of the heliospheric current sheet as the earth would be at

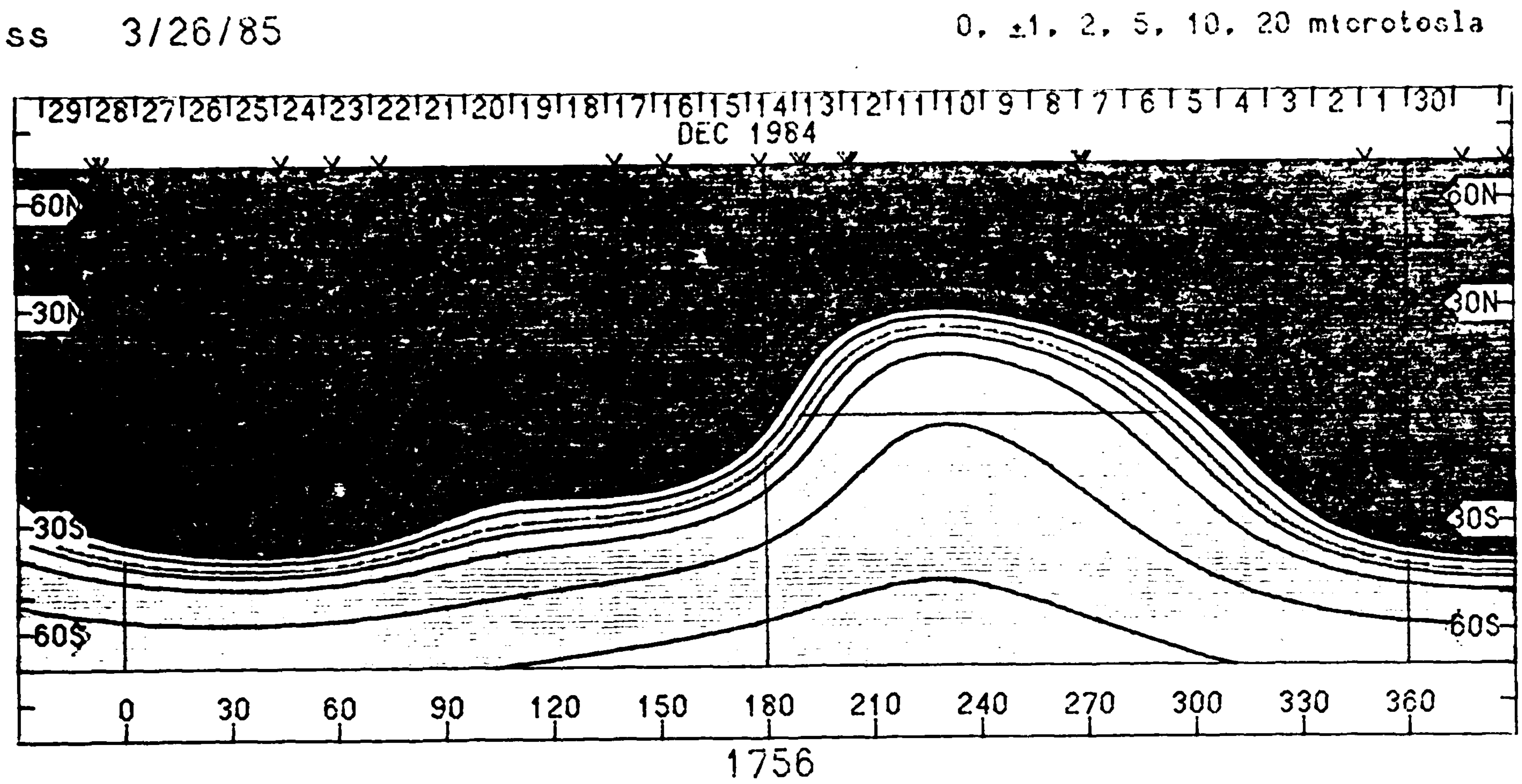

Figure 2. A sample plot from the "Atlas of Photospheric Magnetic Field Observations and Computed Heliospheric Magnetic Fields: 1976 - 1984." This plot shows the computed source surface field for rotation 1756, which was in December 1984. The dark shading shows regions with magnetic fields directed toward the sun and light shading regions with the field directed away from the sun

the time the flare accelerated solar wind material would reach the earth. The flares on the opposite side of the current sheet were classified in the second group. We then examined the solar wind response to all flares in the two groups. We found a strong relationship such that flares on the same side of the current sheet tend to produce larger disturbances than flares on the opposite side.

This effect is likely due to an interaction of the flare material with the slow speed and high density solar wind near the current sheet rather than the current sheet itself. To further understand this effect, one should make a case study of a set of flares for which spacecraft data is available at several heliocentric distances.

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American Geophysical Union Fall Meeting, San Francisco, California. December 8-13, 1985:

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"The Detection of Global Convective Wave Flows on the Sun", P.H. Scherrer, and H. Yoshimura.

"Observations of Low-Degree P-Mode Oscillatons in 1984", H.M. Henning, and P.H. Scherrer.

"Comments on Techniques for Spectral Deconvolution", P.H. Scherrer.

19th ESLAB Symposium, Noordwijk, The Netherlands, June 1985:

"Relationship of the Large-Scale Solar Field to the Interplanetary field: What Will Ulysses Find?", J.T. Hoeksema.

Marshall Space Flight Center, Huntsville, Alabama, August 15, 1985:

"Large-scale Solar Magnetic and Velocity Fields", J.T. Hoeksema.

1985 Meeting of the Solar Physics Division, American Astronomical Society, Tucson, Arizona, May 13-15, 1985:

"The Detection of Global (Giant Cell) Convective Wave Flows on the Sun", H. Yoshimura, P.H. Scherrer, R.S. Bogart, & J.T. Hoeksema.

"Deconvolution Methods for Analysis of Solar Oscillation Observations", P.H. Scherrer.

"Observations of Low-Degree P-Mode Oscillations in 1984", H.M. Henning, P.H. Scherrer.

"A 151-Day Periodicity of Flare Occurrence Observed in Microwave Data", R.S. Bogart, & T. Bai.

Seminar, Institut D'Astrophysique, Paris, France, March 14, 1985:

"The Structure and Evolution of the Heliospheric Magnetic Field", J. Todd Hoeksema.

R.G. Giovanelli Commemorative Colloquium, Part II, "Current Controversies in Solar Magnetic Fields", Tucson, Arizona, January 17-18, 1985:

"Strength of Magnetic Elements During Solar Cycle", P.H. Scherrer.

American Geophysical Union Fall Meeting, San Francisco, California, December 3-7, 1984:

"The Influence of the Heliospheric Current Sheet on Flare Accelerated Solar Wind", H. Henning, J.T. Hoeksema, & P.H. Scherrer.

Solar Neighborhood Meeting, California State at Northridge, November 2, 1984:

"Change in Magnetic Elements During the Solar Cycle", P.H. Scherrer.

"Relationship Between Geoeffectiveness of Flares and the Current Sheet", H. Henning.

S*T*A*R Laboratory, Radioscience Seminar, Stanford, California, November 19, 1984:

"Helioseismology as a Probe of the Sun's Interior", P.H. Scherrer

Observatoire du Nice, Nice, France, October 8, 1984:

"Structure and Evolution of the Large Scale Solar and Heliospheric Magnetic Fields", J.T. Hoeksema.

The Hydromagnetics of the Sun -- Fourth European Meeting on Solar Physics, Noordwijkerhout, The Netherlands, 1-3 October, 1984:

"Harmonic Analysis of the Solar Magnetic Field", J.T. Hoeksema & P.H. Scherrer.

164th Meeting of the American Astronomical Society, Baltimore, Maryland, June 10-13, 1984:

"Harmonic Analysis of the Solar and Heliospheric Magnetic Fields", J.T. Hoeksema and P.H. Scherrer.

American Geophysical Union Spring Meeting, Cincinnati, Ohio, May 14-17, 1984:

"New Views of the Solar Interior", P.H. Scherrer (Invited Review).

XVIII General Assembly of the International Union of Geodesy and Geophysics, Hamburg, West Germany, August 1983:

"Boundary Conditions for a Predictive Numerical Model of the Large Scale Structure in the Interplanetary Medium," S.T. Suess, M. Dryer, J.M. Wilcox, J.T. Hoeksema, and H. Henning.

"The Structure of the Heliospheric Current Sheet: 1976-1982," J.T. Hoeksema and J.M. Wilcox.

"Solar Activity, Interplanetary Dynamics and Terrestrial Disturbances," N.R. Sheeley, Jr., and J.T. Hoeksema.

Lund University, Lund, Sweden, *August 1983 (Invited Talks):*

"The Structure of the Heliospheric Current Sheet: 1976-1982," J.T. Hoeksema.

Solar Seismology from Space Conference, Snowmass, Colorado, August 1983:

"The Problems of Long Duration Observations from the Ground," *Philip* H. Scherrer.

European Physical Society Study Conference on Oscillations as a Probe of the Sun's Interior, Catania, Italy, June 1983:

"Detection of Solar Gravity Mode Oscillations," Philip H. Scherrer and Philippe Delache.

American Astronomical Society, Solar Physics Division Meeting, Pasadena, California, June 22, 1983:

"Empirically Derived Solar Wind Conditions Near the Sun," S.T. Suess, M. Dryer, J.M. Wilcox, J.T. Hoeksema, and H. Henning.

American Geophysical Union Spring Meeting, Baltimore, Maryland, May 1983:

"Review of Sun-as-a-Star Observations of Low Degree Oscillations," Philip H. Scherrer (Invited Review).

Space Environment Laboratory, Boulder, Colorado, May 27, 1983*:*

"The Structure of the Heliospheric Current Sheet: 1976-1982," J. Todd Hoeksema.

Lockheed Palo Alto Research Laboratories, Palo Alto, California, February 24, 1983:

"The Heliospheric Current Sheet," John M. Wilcox (Invited Paper).

University of Alexandria, Alexandria, Egypt, January 4, 1983:

"The Heliospheric Current Sheet," John M. Wilcox (Invited Paper).

American Geophysical Union Fall/Winter Meeting, San Francisco, California, December 7-15, 1982:

"The Three Dimensional Structure of the Heliospheric Current Sheet: 1978-1981," J. Todd Hoeksema, John M. Wilcox and Philip H. Scherrer.

"The Korean Records of the Period of AD 1500-1750 and the SAR Arc," Z.W. Zhang.

"Temporal Variation in the Computed Vorticity Area Index," John M. Wilcox, Philip H. Scherrer, and J. Todd Hoeksema.

Solar Wind 5 Conference, Woodstock, Vermont, November 1-5, 1982:

"The Interplanetary Current Sheet and Its Relation to Coronal Structure," John M. Wilcox and A.J. Hundhausen.

Second International Symposium on Solar Terrestrial Influences on Weather and Climate, Boulder, Colorado, August 2-6, 1982:

"The Interplanetary Magnetic Field and Tropospheric Circulation," John M. Wilcox (Invited Paper).

International Astronomical Union, Colloquium No. 102, Solar and Stellar Magnetic Fields: Origins and Coronal Effects, ETH Zurich, Switzerland, August 2-6, 1982:

"The Structure of the Heliospheric Current Sheet in Early Sunspot Cycle 21," Philip H. Scherrer, J. Todd Hoeksema, and John M. Wilcox.

Pulsations in Classical and Cataclysmic Variable Stars Conference, Joint Institute for Laboratory Astrophysics, Boulder, Colorado, June 1-4, 1982:

"Review of Observations Relevant to Solar Oscillations," Philip H. Scherrer (Invited Paper).

1982 American Geophysical Union Spring Meeting, Philadelphia, Pennsylvania, May 31-June 4, 1982:

"The Structure of the Heliospheric Current Sheet in Early Sunspot Cycle 21," J. Todd Hoeksema, John M. Wilcox, Philip H. Scherrer.

Invited Lectures delivered by John M. Wilcox at Yunnan Observatory, Kunming; Peking University; Purple Mountain Observatory, Nanking; Space Science Institute, Tokyo; Tohoku University, Sendai; and Nagoya University; April and May 1982:

"The Heliospheric Current Sheet"

"Helioseismology"

"Recent Sun-Weather Research"

"Solar Flare Acceleration of Solar Wind"

Naval Postgraduate School, Monterey, California, February 12, 1982:

"How the Sun Fills the Heliosphere with Magnetic Field," John M. Wilcox (Invited Paper).

159th American Astronomical Society Meeting, Boulder, Colorado, January 10-13, 1982:

"Absolute Spectroscopic Measurements of the Solar Equatorial Rotation Rate," J.L. Snider.

"Global Solar Oscillations: High Order Modes with Degree 3 to 5," P.H. Scherrer and J.M. Wilcox.

1981 American Geophysical Union Fall Meeting, San Francisco, California, December 7-11, 1981:

"Helium in the Solar Wind," G. Borrini (Invited Paper).

"Automated Computer Studies of IMF Influence on Tropospheric Trough Development," C.R. Clauer, J.M. Wilcox, P.H. Scherrer, W.O. Roberts, and B.D. Springer.

"Comparison of Solar and Interplanetary Magnetic Structures," J.T. Hoeksema, P.H.

Scherrer, and J.M. Wilcox.

"Internal Structure and Classification of Sector Boundaries," X. Zhao, J.M. Wilcox, and P.H. Scherrer.

Second University College London, Astronomy Colloquium, "Solar and Stellar Magnetism and Rotation," Windsor Great Park, Great Britain, U.K., September 1981:

"Solar Flare Acceleration of Solar Wind: Influence of Active Region Magnetic Field," J.M. Wilcox, H. Lundstedt, and P.H. Scherrer.

International Astronomical Union, Colloquium No. 66, Crimean Astrophysical Observatory, September 1981 (Invited Papers):

"On the Analysis of Long-period Oscillation Data," P.H. Scherrer and J.M. Wilcox. "A Reanalysis of the Low-frequency Data from Stanford and the Crimea; Latest Stanford Observations," P.H. Scherrer and J.M. Wilcox.

Second Cambridge Workshop on Cool Stars, Stellar Systems, and the Sun, Harvard-Smithsonian Center for Astrophysics, Cambridge, Masschusetts, October 21-23, 1981:

"Modification of Average Coronal Properties in the Presence of Periodic Temperature and Density Variations Near the Base," Steven T. Suess.

Auroral Magnetospheric Workshop, Oulu, Finland, August 1981:

"Is Energy Storage and Release Part of the Substorm Process?" Robert C. Clauer (Invited Paper).

4th International Association of Geomagnetism and Aeronomy Scientific Assembly, Edinburgh, Scotland, U.K., August 3-15, 1981:

"Solar Flare Acceleration of Solar Wind: Influence of Active Region Magnetic Field," P.H. Scherrer, J.M. Wilcox, and H. Lundstedt.

"An Analysis of Shock Waves and High Helium Abundance Events Observed at 1 A.U. from 1971 through 1978," G. Borrini, J.T. Gosling, J.R. Asbridge, S.J. Bame, and W.C. Feldman.

"Magnetic Reconnection in Coronal Streamers," R.A. Kopp, G. Borrini, and G. Noci.

"Solar Wind Control of Geomagnetic Activity," C.R. Clauer and R.L. McPherron.

158th American Astronomical Society Meeting, University of Calgary, Alberta, Canada, June 28 - July 1, 1981:

"Recent Global-Scale Oscillations and Magnetic Field Observations," P.H. Scherrer (Invited Paper).

1981 American Geophysical Union Spring Meeting, Baltimore, Maryland, May 25-29, 1981:

"Solar Flare Acceleration of Solar Wind: Influence of Active Region Magnetic Field," J.M. Wilcox, H. Lundstedt, and P.H. Scherrer.

"Solar Wind Accelerated by Class 2 Flares Occupies a Large Solid Angle," H. Lundstedt, J.M. Wilcox, and P.H. Scherrer.

"Solar Wind Control of the Low Latitude Disturbance Field Asymmetry," C.R. Clauer, R.L. McPherron, G. Siscoe, and N. Crooker.

"Magnetic Reconnection in Coronal Streamers," R.A. Kopp, G. Borrini, G. Noci, and J. Brackbill.

"An Analysis of Shock Waves and High Helium Abundance Events Observed at 1 A.U. from 1971 through 1978," G. Borrini, J.T. Gosling, J.R. Asbridge, S.J. Bame, and W.C. Feldman.

19th American Institute of Aeronautics and Astronautics Aerospace Sciences Meeting, Sun/Weather Relationships Session, St. Louis, Missouri, January 1981:

"The Solar and Interplanetary Magnetic Sector Structure and the Weather," J.M. Wilcox (Invited Paper).

157th American Astronomical Society Meeting, Albuquerque and Taos, New Mexico, January 1981:

"Polar Coronal Plumes," S.T. Suess.

"Solar Wind Helium and Hydrogen Structure Near the Heliospheric Current Sheet - A Signal of Coronal Streamers," G. Borrini, J. Gosling, S. Bame, W. Feldman, and J. Wilcox.

"Coronal Streamers in the Solar Wind," G. Borrini, J. Asbridge, S. Bame, W. Feldman, and R. Hansen.

1980 American Geophysical Union, San Francisco, California, December 8-12, 1980:

"Low Helium Abundance - A Signal of Coronal Streamers in the Solar Wind," G. Borrini, J.T. Gosling, S. J. Bame, W.C. Feldman, and J. M. Wilcox.

"Coronal Streamers in the Solar Wind," G. Borrini, J. T. Gosling, and R. T. Hansen.

Bay Area Chapter Meeting, Stanford Research Institute, Menlo Park, California, November 20, 1980:

"Possible Influence of the Solar Magnetic Field on Tropospheric Circulation," John M. Wilcox (Invited Paper).

Lockheed Research Colloquium, Palo Alto, California, November 13, 1980:

"Solar Magnetic Structure and the Weather," John M. Wilcox (Invited Paper).

Sun and Climate International Conference, Toulouse, France, October 1, 1980:

"Possible Influences of Solar Rotation on Tropospheric Circulation," John M. Wilcox (Invited Paper).

XIVth ESLAB Symposium on Physics of Solar Variations, Scheveningen, The Netherlands, September 16-19, 1980:

"Solar Oscillations with a Period of 160 Minutes and with a Period of 5 Minutes," Philip H. Scherrer.

"Further Investigation of the Solar Torsional Oscillator with a Period of 11 Years," Philip H. Scherrer.

"On the Nature of the Apparent Response of the Vorticity Area Index to the Solar Magnetic Field," John M. Wilcox.

"The Corona and the Large Scale Magnetic Field of the Sun," Steven T. Suess.

"The Origin of the Warped Heliospheric Current Sheet," John M. Wilcox.

156th Meeting of the American Astronomical Society, University of Maryland, College Park, Maryland, June 15-18, 1980:

"Further Investigation of the Solar Torsional Oscillator with a Period of 11 Years," Philip H. Scherrer.

"A Two-Sector Solar Magnetic Structure with 29 Day Rotation," J. Todd Hoeksema, Philip H. Scherrer, John M. Wilcox.

"Solar Activity and the Weather," John M. Wilcox (Invited Paper), Los Alamos Scientific Laboratory, Los Alamos, New Mexico, June 10, 1980.

American Geophysical Union, Spring Meeting, Toronto, Ontario, Canada, May 22-27, 1980:

"A New Mid-Latitude Solar Magnetic Feature," Philip H. Scherrer, J. Todd Hoeksema, and John M. Wilcox.

"The Origin of the Warped Heliospheric Current Sheet," John M. Wilcox, J. Todd Hoeksema, and Philip H. Scherrer.

"On the Nature of the Apparent Response of the Vorticity Area Index to the Solar Magnetic Field," John M. Wilcox, Philip H. Scherrer, and J. Todd Hoeksema.

"Dynamics and Abundance of Ions in Coronal Holes," Grazia Borrini.

"Terrestrial Effects of Solar Magnetic Fields," John M. Wilcox, Harvard Medical School, Cambridge, Massachusetts, January 22, 1980.

155th Meeting of the American Astronomical Society, San Franciso, California, January 13-16, 1980:

"Geomagnetic Activity and Hale Sector Boundaries," Henrik Lundstedt.

"Solar Oscillations with a Period Near 160-Minutes," Philip H. Scherrer.

154th Meeting of the American Astronomical Society, Wellesley, Massachusetts, June 11-14, 1979:

"Solar Rotation - Observations at Stanford Since 1976," Philip H. Scherrer.

American Geophysical Union, Spring Meeting, Washington, D.C., May 28- June 1, 1979:

"The Variation with Time of a Sun-Weather Effect," John M. Wilcox.

"Observations of Solar Oscillations with Periods of 160 Min. at the Stanford Solar Observatory and at the Crimean Astrophysical Observatory," Philip H. Scherrer.

Lawrence Hall of Science, University of California, Berkeley, California, February 8, 1979:

"The Sun's Magnetic Field and Our Weather," John M. Wilcox.

8th Technical Exchange Conference, United States Air Force Academy, Colorado, November 28 - December 1, 1978:

"Solar/Terrestrial Meteorological Relationshiops," John M. Wilcox (Invited Paper).

Sonoma State College, Department of Physics and Astronomy," October 23, 1978:

"The Sun as a Star," Philip H. Scherrer (Invited Talk).

Workshop on Solar Rotation, Catania, Sicily, September 26-29, 1978:

"The Equatorial Rotation Velocity of the Photosphere is Measured to be the Same as Sunspots," John M. Wilcox (Invited Paper).

Symposium on Large-Scale Motions on the Sun, Sacramento Peak Observatory, Sunspot, New Mexico, September 1-2, 1978:

"2 h 40 m Oscillation Observations at Stanford," Philip H. Scherrer.

Symposium/Workshop on Solar Terrestrial Influences on Weather and Climate, Ohio State University, Columbus, Ohio, July 24-28, 1978:

"Influence of the Solar Magnetic Field on Tropospheric Circulation," John M. Wilcox (Invited Paper).

COSPAR Meeting, Innsbruck, Austria, May/June 1978:

"Solar Activity and Changes in Atmospheric Circulation," John M. Wilcox.

Seminar, Institute for Plasma Physics, Stockholm, Sweden, May 25, 1978:

"A Survey of Recent Sun-Weather Research," John M. Wilcox.

American Geophysical Union, Spring Meeting, Miami, Florida, April 17-21, 1978:

"Influence of the Changing Sun on Weather and Climate," John M. Wilcox (Invited Paper).

"Statistical Significance of the Influence of the Interplanetary Magnetic Sector Polarity on the Area of Low-Pressure Troughs in the Gulf of Alaska," Kenneth H. Schatten.

"An Attempt to Define the Geophysical Area Near the Gulf of Alaska in Which a Physical Relationship Exists Between the Interplanetary Magnetic Secotor Polarity and the Area of Low- Pressure Troughs," John M. Wilcox, Kenneth H. Schatten, Philip H. Scherrer, Walter O. Roberts, and Roger Olson.

Effects of Solar Processes on Atmospheric Phenomena, Geophysics Colloquium, University of Washington, Seattle, Washington, April 11-12, 1978:

"Solar Magnetic Field and Weather," John M. Wilcox.

"Solar Magnetism for Meteorologists," John M. Wilcox.

Naval Environmental Predictions Research Facility, Monterey, California, April 10, 1978:

"Possible Use of Sun-Weather Relationship in Numerical Weather Forecasting," John M. Wilcox.

Naval Postgraduate School, Monterey, California, March 9-10, 1978:

"Solar Activity and the Weathr," John M. Wilcox.

California Institute of Technology, Pasadena, California, February 17, 1978:

"Influence of the Changing Sun on Weather and Climate," John M. Wilcox.

University of California-Los Angeles, Los Angeles, California, Februry 16, 1978:

"Influence of the Changing Sun on Weather and Climate," John M. Wilcox.

Solar-Terrestrial Coupling Conference, Yosemite, California, February 8-11, 1978:

"Periodocities in Solar Activity," Kenneth H. Schatten.

"Evidence for Magnetospheric-Weather Relationship," John M. Wilcox.

"The Influence of interplanetary Magnetic Sectors on Tropospheric Cyclones," John M. Wilcox.

AIAA 14th Annual Meeting, Washington, D.C., February 6-10, 1978:

"Solar Activity and the Weather," John M. Wilcox.

American Geophysical Union, Fall Annual Meeting, San Francisco, California, December 5-9, 1977:

"Influence of Interplanetary Magnetic Polarity on the Area of Tropospheric Troughs," Philip B. Duffy, John M. Wilcox, Walter Orr Roberts, and Roger H. Olson.

"The Strength of the Sun's Polar Fields," Leif Svalgaard.

IAGA/IAMAP Joint Symposium, Seattle, Washington, August 22 - September 3, 1977.

"Morphology of a Sun-Weather Effect," John M. Wilcox, Philip H. Scherrer, Leif Svalgaard, and Eric K. Gustafson.

NASA Ames Research Center, Moffett Field, California, April 26, 1977:

"Recent Sun-Weather Investigations," John M. Wilcox (Invited Talk).

Topical Conference on Solar and Interplanetary Physics, American Astronomical Society, Tucson, Arizona, January 12-15, 1977:

"Large-Scale Periodic Solar Velocities," Philip H. Dittmer, Philip Scherrer, and John M. Wilcox.

"The Hale Solar Sector Boundary," John M. Wilcox and Leif Svalgaard.

"Comparison of Ho Synoptic Charts with the Large-Scale Solar Magnetic Field as Observed at Stanford," Thomas L. Duvall, John M. Wilcox, Leif Svalgaard, Philip Scherrer, and Patrick McIntosh.

"Three-Dimensional Structure of the Interplanetary Magnetic Field," Leif Svalgaard and John M. Wilcox.

"The Solar Source of the Interplanetary Magnetic Field," Philip Scherrer.

Lectures and papers delivered before 1977 available on request.

HARMONIC ANALYSIS OF THE SOLAR MAGNETIC FIELD

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Abstract

The spherical harmonics of the global solar magnetic field have been calculated using photospheric field measurements from the Stanford Solar Observatory from 1976 - 1983. Near minimum the heliospheric field is predominantly a dipole field with a small quadrupole warp which influences the interplanetary medium at the Earth's latitude. Near solar maximum the magnitudes of the quadrupole and octopole components are comparable to the dipole. During most of the cycle the field cannot be adequately described as simply a dipole or tilted dipole.

The polar and equatorial components of the dipole evolve independantly which means that the field evolution during the solar cycle should not be described as a "rotating dipole."

The amplitude modulation of the harmonics is suggestive of a beating phenomenon among a few signals with closely spaced periods. Spectral analysis of the equatorial dipole shows dominant peaks at 27.0 and 28.2 days. The higher order harmonics have similar characteristics.

Keywords: Coronal Structure, Heliospheric Field, Solar Cycle

The configuration of the heliospheric field changes substantially during the solar cycle. Near solar minimum the structure is quite simple. The current sheet, which marks the surface dividing regions of interplanetary field (IMF) pointing toward and away from the sun, lies near the equator with small warps producing the 4-sector structure observed in the IMF near Earth. During the rise to maximum, the latitudinal extent of the current sheet increases as the strong polar fields weaken and eventually reverse sign. Near maximum the complexity of the field may even produce multiple current sheets. The declining phase of the cycle can be characterized by strengthening polar fields, simplification of the magnetic structure, and the development of very stable heliospheric magnetic field patterns.

The preceeding picture can be inferred from spacecraft measurements of the IMF, comet tail observations, coronal hole locations, interplanetary scintillation measurements of the solar wind speed, coronameter polarization brightness data, and from computations of the coronal field from photospheric observations (Refs. 1-8).

Using the photospheric field measurements from the Stanford Solar Observatory and a potential field - source surface model of the coronal magnetic field, we have calculated the field structure in the low corona. In this method the field is specified in terms of the various spherical harmonic modes, viz. dipole, quadrupole, octupole, etc. The solar wind carries the field configuration at the source surface radially outward into the heliosphere. Since the structure is 'locked in' at 2.5 solar radii, the relative magnitudes of the multipole moments describing the location of the current sheet do not change with increasing distance from the sun.

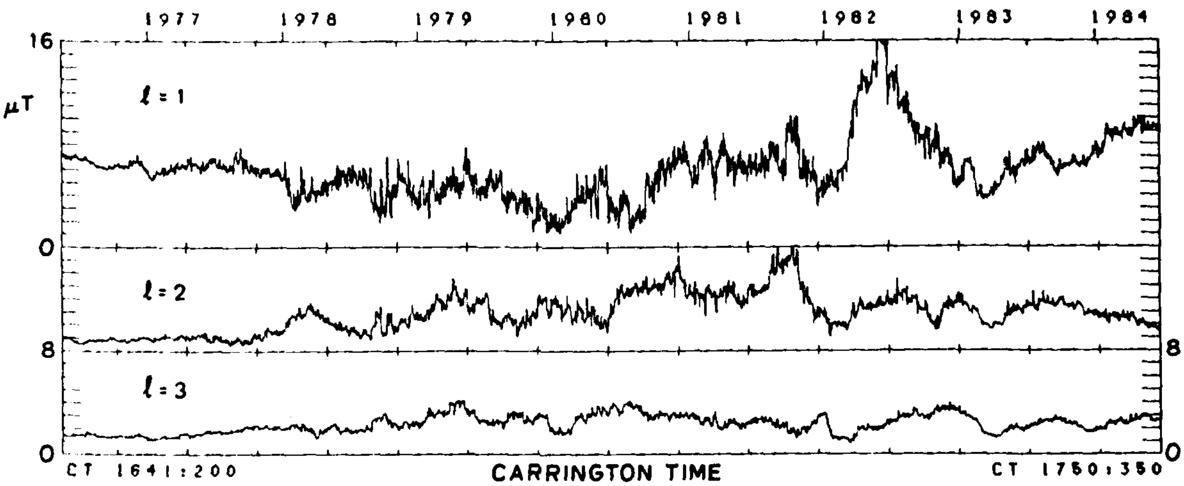


Figure 1: RMS value of the field at the source surface due to the dipole (l=1), quadrupole (l=2), and octupole (l=3) multipoles from May 1976 through June 1984. All are plotted on the same scale.

Proceedings of the Fourth European Meeting on Solar Physics – 'The Hydromagnetics of the Sun' –, Noordwijkerhout, The Netherlands, 1-3 Oct. 1984 (ESA SP-220, Nov. 1984).

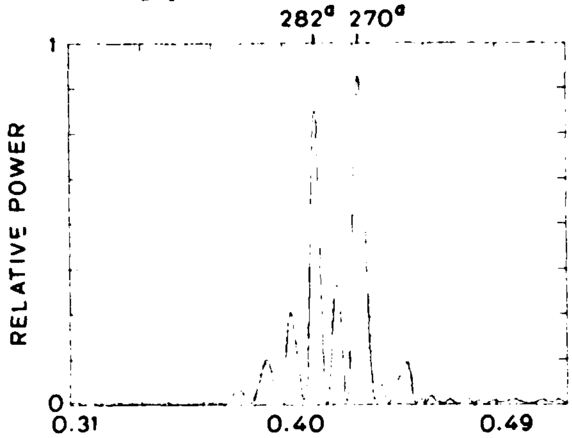
Figure 1 shows the rms value of the field strength at the base of the heliosphere (the "source surface") due to the dipole, quadrupole and octupole moments. Stanford's synoptic observations of the photospheric field began in May 1976, near minimum, and continue to the present time. All the components are plotted on the same scale and show the relative contributions to the heliospheric rms field strength.

During 1976, 1977, 1984, and part of 1982 the dipole was the largest component. During the other 5 years the quadrupole and sometimes the octupole were of about the same magnitude. Even near minimum the quadrupole greatly influenced the IMF structure observed at Earth. The heliospheric field cannot usually be described just in terms of a dipole.

Does the solar dipole field rotate slowly from north to south as the polar fields reverse near solar maximum? (Ref. 9) If so, the equatorial and polar components of the dipole should evolve together so that as the polar component weakens the equatorial component strengthens, like sine and cosine waves. Figure 2 shows the polar (m=0) and equatorial (m=1) components of the dipole. The m=0 mode is strong near minimum, weakens and reverses around maximum, and strengthens during the early declining phase of the solar cycle. The equatorial component strengthens as maximum approaches, but remains about as strong as the polar field during the following years and varies considerably. Even ignoring the substantial contribution of the higher multipole moments, this suggests that the two dipole components are really largely independant and do not form a rotating dipole.

The strong sinusoidal nature of the equatorial dipole component results from the rotation of the sun. The amplitude modulation of the signal is suggestive of a beating of a few signals with similar frequencies. Figure 3 shows the power spectrum of the equatorial dipole component shown in Figure 2. All of the power is clustered near the solar rotation period with the largest peaks at periods of 27.0 and 28.2 days. The same frequencies dominate when the signal is divided into successive 3 year intervals. The higher order harmonics show similar organization, though not as clearly as the dipole. One would expect differential rotation to smear out any large scale organization of the equatorial dipole rather than show organization into two discreet frequencies. Not surprisingly, the pattern of IMF polarity recurs with the same two periods.

Figure 3: The power spectrum of the equatorial dipole shows two large peaks at 27.0 and 28.2 days.



The equatorial dipole field shows both 27 day and 28.2 day rotations rates, similar to patterns in the IMF. Explanation of this phenomenon will require further investigation.

Conclusions

The configuration of the heliospheric field can be characterized in terms of the first few multipole moments. Except near minimum, the field should not be referred to as a simple dipole field.

The reversal of the polar fields occurs gradually as the polar component of the the field weakens, reverses, and strengthens. The equatorial dipole evolves independantly.

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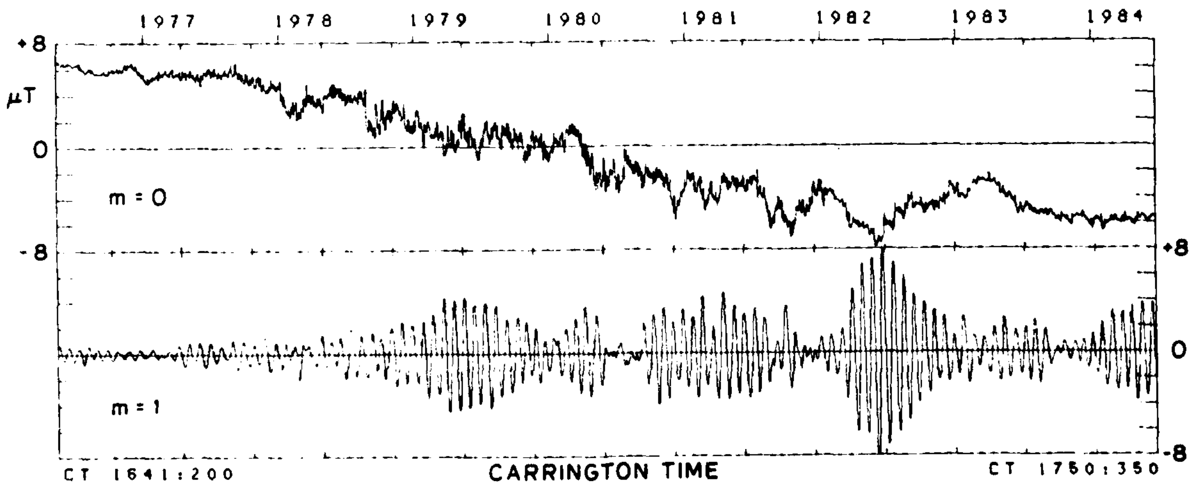

Figure 2: The polar (m=0) and equatorial (m=1) components of the dipole field from May 1976 through June 1984. The polar dipole reversed near maximum at the end of 1979. The dipole component varies as the sun rotates.

The Influence of the Heliospheric Current Sheet and Angular Separation on Flare Accelerated Solar Wind

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Abstract. A complete set of major flares has been used to investigate the effect of the heliospheric current sheet on the magnitude of the flare-associated disturbance measured at Earth. It was found that disturbances associated with flares located on the same side of the current sheet as Earth were of larger magnitude than those associated with flares located such that the flare-accelerated material would have to cross the current sheet. It was also found that the angular separation between the flare position and Earth has a strong effect on the magnitude of the disturbance. A larger angular separation tended to result in a smaller disturbance. Thirdly, it was determined that flares tend to occur near the heliospheric current sheet.

1. Introduction

It is known that flares produce disturbances in the solar wind resulting in geomagnetic activity at Earth. However, the magnitude of such disturbances cannot yet be predicted for any given flare. This paper presents the results of a statistical analysis which separates and identifies some of the quantities which determine the relative magnitude of a flare-associated disturbance. The main thrust of the analysis is to determine the effect of the relationship between the location of the flare and the location of the heliospheric current sheet (HCS). To avoid bias in the estimate of an HCS effect, however, one must also examine any effect due to the position of the flare on the solar disk. This analysis produces two major results: First, that flares occurring on the opposite side of the HCS from the earth produce smaller solar wind and geomagnetic disturbances than those on the same side. Second, we find that the disturbance decreases with *increasing* angular distance of the flare from the sub-earth point.

Three kinds of data were used in the present study. The first is the list of major flares as defined by Dodson and Hedeman (1971, 1975, 1981). The second is the location of the HCS as computed by Hoeksema (1982, 1983, 1984, 1985). The third is the indicator of solar wind response to the flare, and has been taken to be the geomagnetic disturbance index D_{ST} and solar wind velocity when available.

2. Data

The flares used in this analysis are taken from the UAG reports of the Comprehensive Flare Index (CFI) compiled by Helen W. Dodson and E. Ruth Hedeman (1971, 1975, 1981). These records contain a complete list of all observed major flares from 1955-1979. The CFI is comprised of five components:

1) Importance of ionizing radiation as indicated by time-associated Short Wave Fade or Sudden Ionospheric Disturbance (Scale 0-3).

2) Importance of Hα flare (Scale 0-3).

3) Magnitude of $\approx 10cm$ flux; (characteristic of log of flux in units of $10^{-22} Wm^{-2} Hz^{-1}$); (Scale 0-4).

4) Dynamic spectrum; (Type II = 1, Continuum = 2, Type IV with duration > 10 min = 3); (Scale 0-3).

5) Magnitude of ca. $200MHz$ flux; (characteristic of log of flux in units of $10^{-22} Wm^{-2} Hz^{-1}$); (Scale 0-5).

The total CFI of a flare is then just the sum of the 5 components, with a possible range of 1 to 18.

A major flare is defined as one which was well above average in either ionizing, $H\alpha$, or radio frequency radiation (corresponding CFI component ≥ 3), or exhibited a Type II burst or Type IV burst with longer than 10 min duration (Dodson and Hedeman 1971, 1975, 1981). From this still formidable list the data for this analysis was selected by including only flares with a total CFI of 7 or greater. For the interval from 1968 through 1979 the data includes 505 flares. Missing data for the flare position or solar wind parameters reduces this number to slightly more than 400. All these flares were used for the part of the analysis determining the disk-position dependence of solar wind disturbances.

The location of the heliospheric current sheet (HCS) is derived from the potential field model calculations done at Stanford (Hoeksema 1982, 1983, 1984, 1985). The HCS data starts in the middle of 1976, and continues to the present. For the HCS analysis then, the flares from 1976 to 1979 were used. The majority of these occurred in 1978 and 1979, as the solar cycle maximum was approaching. There are 181 flares in this interval, of which slightly more than 140 remain after elimination of those with missing positions or solar wind data.

The geomagnetic index D_{ST}, which is continuously available and proportional to solar wind speed and B_z (Murayama 1982), and the solar wind speed hourly averages observed by ISEE3 are used to measure the flare generated disturbance. Figures 1 and 2 show superposed epoch analyses of solar wind speed and D_{ST} about flare times. These plots show a strong peak in the disturbance of the solar wind and D_{ST} 2 to 4 days after the flare. Note that a higher value for solar wind speed is the signature of a disturbance, whereas for D_{ST} it is a lower, i.e. greater negative, value. We chose to examine 24-hour averages of these two indices to study the effect of flare position on the disk and relative to the HCS. Use of the 24-hour averages has the advantage that it avoids the subjectivity that occurs when one attempts to identify the source of a particular disturbance. An analysis of 24-hour intervals in the period from 1.0 to 4.5 days after the flare showed that averages of the interval from 2.0 to 3.0 days after the flare demonstrate the effect of the HCS and flare position most strongly. We found that there was a strong HCS effect evident when examining any 24-hour interval between 1.5 and 4.5 days after the flare, beginning sharply at 1.5 days and a gradual decrease commencing 3 days after the flare and continuing past 4.5 days. Thus, for each flare in our study, a 24 hour average was calculated for the interval starting 2 days after the flare.

The time interval chosen allows for a propagation velocity of the flare-accelerated material ranging from 577 km/sec to 866 km/sec. Note that the 24 hour average of the solar wind speed itself will usually be substantially less than this, since the average also includes quiet solar wind. Very likely some of the flare associated disturbances may be missed, but, without making the time intervals too large and further diluting the size of a disturbance, this problem cannot be avoided in a completely objective analysis where we want to avoid the uncertainty in associating a specific solar wind or D_{ST} disturbance with a particular flare.

3. Analysis

3.1. The Heliospheric Current Sheet

To determine whether a flare-associated disturbance had to cross the HCS to reach Earth we looked at the source surface calculated at Stanford with the potential field model (Hoeksema 1982, 1983, 1984, 1985). We assume the steady, undisturbed solar wind carries the magnetic structure of the source surface into interplanetary space, reaching Earth after an average of 5 days. The flare material is assumed to take an average of 2.5 days to reach Earth. Thus we can estimate the magnetic structure at the flare position on the sun and at Earth when the disturbance arrives. Specifically, if the polarities of the magnetic field (either inward directed or outward directed) are different, the flare is considered to be on the opposite side of the HCS, i.e. the flare material has to cross the HCS to reach Earth. If the polarities are the same, the flare is considered to be on the same side of the HCS. If either of the positions was very close to the HCS, i.e. the field magnitude was very small (less than $0.1\mu T$ on the source surface), the flare was eliminated from the analysis. There were four such instances. In addition, two cases where the flare material would have propagated tangential to the HCS were eliminated from the study, since the latitudinal extent of the HCS is uncertain by a few degrees. There were three cases where flare material had to cross two HCS's. The final flare set for the solar wind speed analysis contains 135 flares, of which 75 are on the same side of the HCS and 60 on the opposite side. There were 2 more flares in each category available for the D_{ST} analysis.

We define a quantity D, which we call the difference measure, that provides an indication of the significance of the effect the HCS has on flare-associated disturbances as follows :

$$D = \frac{(\overline{X}_{same} - \overline{X}_{opp})}{(\bar{\sigma}_{X_{same}} + \bar{\sigma}_{X_{opp}})},$$

where X is the quantity with which we are measuring the disturbance, e.g. solar wind speed 3-4 days after the flare.

In words, D is the difference between the average quantity (solar wind speed, D_{ST}) for flares on the same side of the HCS and the average quantity for flares on the opposite side of the HCS, as measured in units of the average error of the mean. Thus, a large absolute value of D is an indicator of an effect.

Figure 3 shows the values of D for solar wind speed 2 to 3 days after the flare. Large positive D means a significantly larger value of average solar wind speed for flares on the same side of the HCS than for flares on the opposite side. In panels a-e the flares were grouped depending on their value for different components of the CFI. The flares in figure 3a were grouped by the value of the first component of the CFI, i.e. by the importance of ionizing radiation. The value of D for all flares which had ionizing radiation importance of 1 or greater is shown at the abscissa "1+", the value of D for all flares with ionizing radiation importance of 2 or greater at abscissa "2+", and so on. Similarly, figure 3b was grouped by Hα importance, 3c by the magnitude of $10cm$ flux, 3d by the dynamic spectrum, and 3e by the magnitude of $200MHz$ flux. Note that the first point in each panel includes all flares with a CFI component value of 0 or greater, i.e. all flares in the data. The reason for this method of grouping is that since flares are selected on the basis of a value of total CFI $\geq$7, a value of 0 in one component of the CFI implies on the average a high value in another component of the CFI. This bias prevents us from examining flares grouped by a particular value of a particular CFI component, rather we examine flares grouped according to whether a CFI component exceeds a given threshold. The adopted grouping enables one to see better the effect large flares have as opposed to smaller ones.

In the final panel, f, flares were categorized by their total CFI value, in the method described above.

Figure 4 has the same format as figure 3, but shows the response of D_{ST} rather than the solar wind speed. In this figure, a large negative value of D indicates an effect, since a more negative value of the D_{ST} index indicates greater geomagnetic activity.

The first and most important thing to be learned from these plots is that there is a definite HCS effect. The flares on the same side of the HCS as the earth result in a larger disturbance, i.e. greater solar wind speed and more negative D_{ST}. The size of this effect is quite large, on the order of 4σ (solar wind speed) or 5σ (D_{ST}), which corresponds to about a 55 km/sec difference in solar wind speed or 18 in D_{ST} units. In order to check for consistency of the effect, the flares were divided into two time intervals and the calculations done separately for each. The resulting plots were practically identical to each other and to the calculations from the full data (figures 3 and 4), demonstrating the consistency convincingly.

None of the components of CFI, nor the total CFI, seems to produce a significantly larger or smaller effect. All the plots look fairly similar, even though for each panel different flares determined the points for CFI component values greater than 0. Thus none of the components of CFI stands out as a determinant for whether a flare will cause a large disturbance or not. Nor does total CFI provide a better organization, although it certainly provides a more complete list of major flares than any of its separate components.

One is tempted to note that in almost all panels, for a higher value of the CFI component the absolute value of D is getting smaller, i.e. perhaps for the truly strongest flares the HCS effect is less. However, another factor contributes to produce this decrease in D. This factor is the definition of D. For the points at larger values of the CFI component there are fewer flares, and thus the error of the mean is larger, giving a smaller value of D. If one examines the actual solar wind speed or D_{ST} difference between the average for flares on the same side and the average for flares on the opposite side, the tendency is actually for the difference to be a larger number. Therefore, contrary to the immediate assumption, it appears that the HCS effect is proportionally stronger for stronger flares. However, the uncertainty of the numbers, as demonstrated by the decrease of D in the plots, means that we cannot provide a concrete answer to this question about large flares.

Summarizing this section, by use of these graphs we have successfully demonstrated that there exists an HCS effect, given an idea of its significance and determined that no component of CFI, i.e. no energy range, stands out as a strong organizer of solar wind disturbances.

3.2. Angular Separation

In the preceding analysis, we found that the position of the flare with respect to the HCS, i.e. same or opposite side, resulted in a significant difference in the size of the flare-associated disturbance. However, to get an unbiased estimate of an effect the HCS has on such disturbances one has to consider a possible systematic effect associated with the angular distance of the flare from the sub-earth position. It is clear that the farther a flare is separated in angular distance from the sub-earth point, the more likely it is that an HCS lies in-between. Thus there is a likely systematic bias that disturbances which have to cross the HCS are due to flares which are at larger angular distances from Earth. We have examined the solar wind response at Earth to a flare as a function of the angular distance between the flare and the sub-earth point. In addition to later enabling us, in our main analysis, to separate the HCS effect from this distance effect, this investigation is, of course, interesting in its own right.

As a first test of the systematic bias, we found that indeed, for the period starting in 1976, where the HCS position is known, and ending in 1979, the end of the CFI compilation, the average angular distance from Earth for flares on the same side of the HCS was 42°, while for those on the opposite side it was 57°.

To judge the effect of this bias we examined the dependence of the solar wind response, as measured by magnitude of solar wind speed or D_{ST}, on the angular separation between the flare and Earth. Since we are not restricted by having to know the location of the HCS, we have taken all flares in our data with known positions, starting with the year 1968 and running through 1979. The angular distance to the sub-earth point at the average time when flare material is assumed to reach Earth, i.e. after 2.5 days, was calculated for each flare. The flares were then binned by distance and the average solar wind speed and D_{ST} plotted in figures 5a and 6a respectively. Figures 5b and 6b show the results of a similar calculation, except that only longitudinal separation was considered.

The graphs clearly show an effect on the average size of the disturbance. The farther Earth is separated in angular distance from the position of the flare, the weaker the disturbance measured at Earth. It is debatable whether the dependence is a monotonic decrease of the disturbance with angular distance, or whether there is a region of about $\pm 40°$ around the flare position where the disturbance is large, and outside of this "bubble" the effect of the flare is much smaller (especially evident for D_{ST}). However, the scatter plot of all flares seems to support a monotonic decrease.

Also, one can argue that there seems to be an East-West asymmetry. For positive longitudinal separation the average magnitude of a disturbance, as measured by high solar wind speed or large negative D_{ST}, seems larger than for corresponding negative longitudinal separation. Thus, it suggests that a flare on the western hemisphere of the sun may have a larger effect than one on the eastern hemisphere. This is consistent with the report that streams from flares on the western hemisphere have a speed 50% higher than those from eastern flares (Pudovkin et al 1979). However, since the uncertainty is fairly large we will consider only the angular distance in the further analysis.

If we assume a roughly linear monotonic decrease, then we can estimate the size of the systematic effect introduced into our HCS analysis. We calculated the average angular distance for flares on the same side of the HCS, 42°, and the opposite side, 57°. Figure 5a shows a difference of about 15 km/sec in average solar wind speed between these two values. Figure 6a provides the same information for D_{ST}, a difference of about 3 D_{ST} units.

3.3. The HCS Effect

Returning to our main investigation of the effect of the HCS on the disturbances caused by flares, we must try to remove the effect of angular distance. To do so, a straight line was fitted to a plot of disturbance (as measured by solar wind speed or D_{ST} measured at Earth 2.0 to 3.0 days after the flare) vs. angular separation for all flares used in the HCS analysis (figures 7a and 7b). These lines then represents the effect of angular distance, although one cannot totally separate the effects since at larger angular distance there are more flares on the opposite side of the HCS, and vice versa for smaller angular distance, influencing the slope of the line such that the HCS effect is weakened by an unknown, although certainly little, amount. In the next step the flares were separated according to whether they were on the same or opposite side of the HCS. For each flare the distance from the line (in appropriate units, i.e. km/sec for solar wind speed, or D_{ST} units) was calculated. Each group, i.e. same and opposite side flares, has a roughly Gaussian distribution. The centroid and error of the mean of these distributions were calculated for both groups of flares. Then the difference between the centroid for flares on the same side of the HCS and the centroid for flares on the opposite side was taken, producing the following results :

$$Solar\ Wind\ Speed\ :\ \overline{same} - \overline{opp.} = 43.4 \pm 19.5\ km/sec\ \ (98.7\% > 0)$$

$$D_{ST}\ :\ \overline{same} - \overline{opp.} = -15.4 \pm 4.6\ (99.9\% < 0)$$

Referring to the values quoted in section 3.1 and 3.2, one sees that the angular distance effect accounts for roughly one fourth of the difference demonstrated in figures 1 and 2. The other three fourths result from the HCS effect.

3.4. Distance from the HCS

As an aside resulting from this analysis, the distance of each flare from the nearest HCS was calculated, giving an average of 16° for flares from September of 1977 to the end of 1979, a period of continuous high activity. There was no significant difference between the average distance for flares on the same side of the HCS and the average distance for those on the opposite side. A set of artificial flare positions was then determined by keeping the actual latitudes (to insure a realistic distribution in latitude) but assigning random Carrington longitudes within this interval. Then the average distance to the HCS for this set was calculated. This process was repeated 400 times. In none of these 400 trials did the average come as low as the true average, the lowest being only 17.5°. The overall average distance between random positions and the HCS for all iterations was 21°. This average is significantly greater than the average resulting from the true flare position. This confirms the tendency for flares to occur near the HCS (Dittmer 1975).

4. Conclusion

In this analysis we have investigated the effect of angular separation and the HCS on flare associated disturbances measured at Earth. We have found that there is a clear association between *proximity* of the flare to the sub-earth point and stronger disturbances. This relation accounts for a fourth of the difference noted between disturbances from flares on the same and opposite sides of the HCS. A strong effect associated solely with the HCS remains at a greater than 98% confidence level. Flares on the same side of the HCS tend to produce larger disturbances than flares on the opposite side. This influence of the HCS may be explained by the fact that solar wind speed tends to be at a minimum along the HCS (Borrini 1981), and thus disturbances in propagating to Earth would have to interact with this slower plasma, perhaps weakening them.

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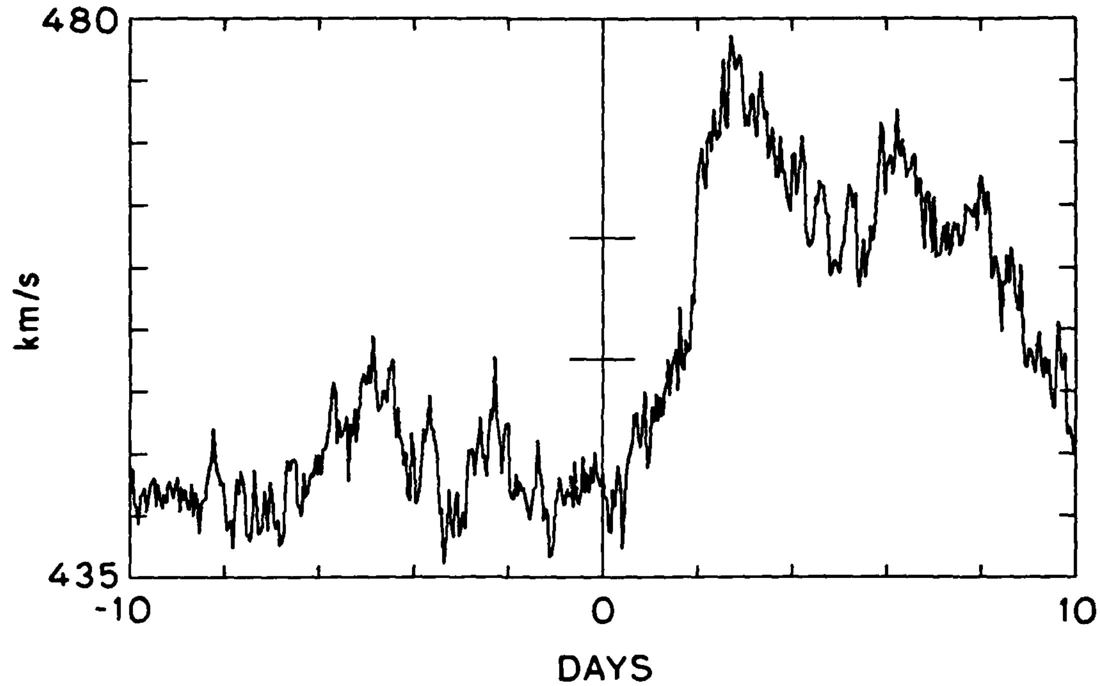

Fig.1. Superposed epoch plot of solar wind speed at Earth around flare times (day 0). A strong peak is evident between 2 and 4 days after a flare. The second peak between 5 and 8 days, as well as the peaks before the flare can be attributed to the fact that flares tend to occur in bunches, so that these peaks are signatures of flares before and after the one at day 0.

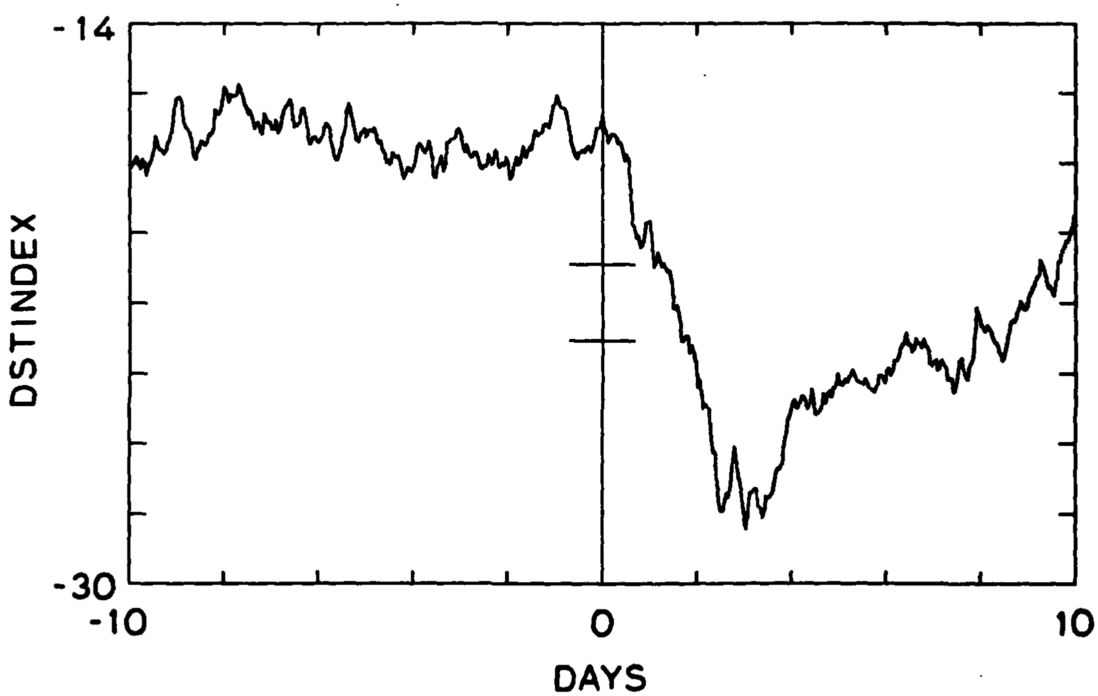

Fig.2. The same as figure 1, but for D_{ST} rather than solar wind speed. The size of the peak in activity (dip in D_{ST}) is relatively greater than for solar wind speed.

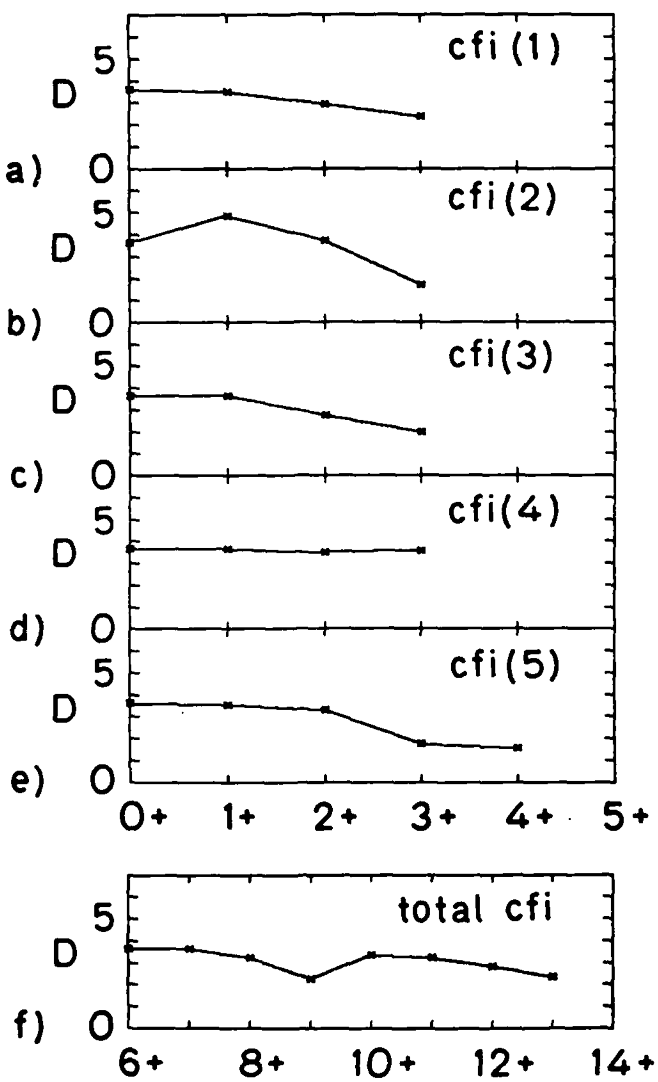

Fig.3. Graphs of the difference measure D for solar wind speed vs. magnitude of the flare as measured with a) importance of ionizing radiation, b) importance of H_α flare, c) magnitude of $10cm$ flux, d) dynamic spectrum, e) magnitude of $200Hz$ flux, and f) total CFI. In each panel, D runs from 0 (bottom) to 7 (top).

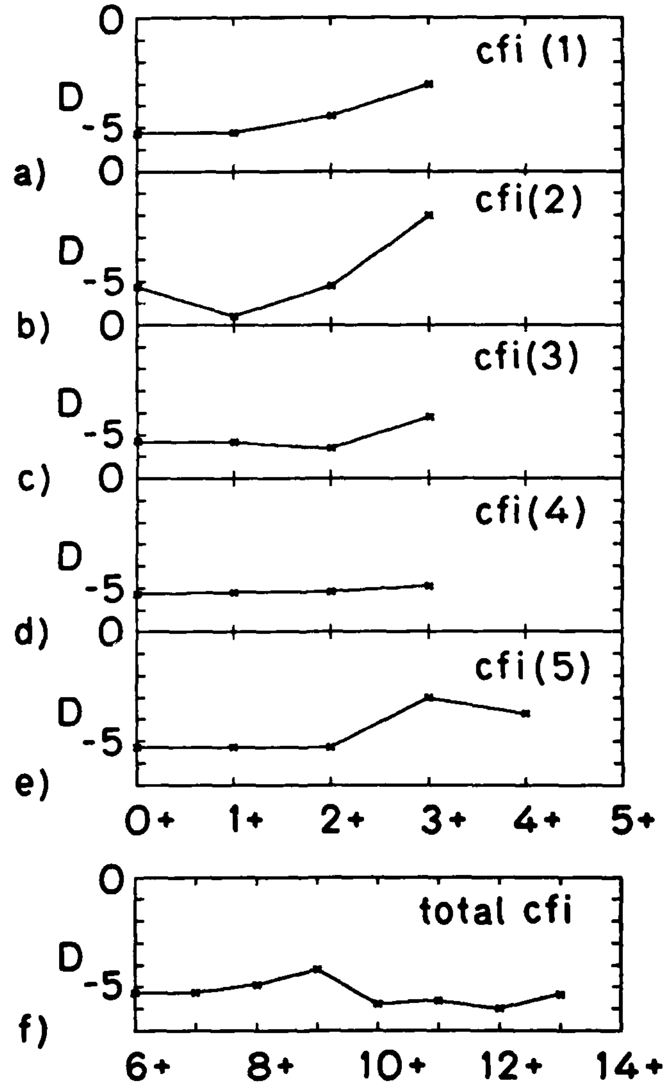

Fig.4. The same as figure 3, but for D_{ST} rather than solar wind speed. The magnitude of D is greater than for solar wind speed, otherwise the graphs are very similar. In each panel, D runs from -7 (bottom) to 0 (top).

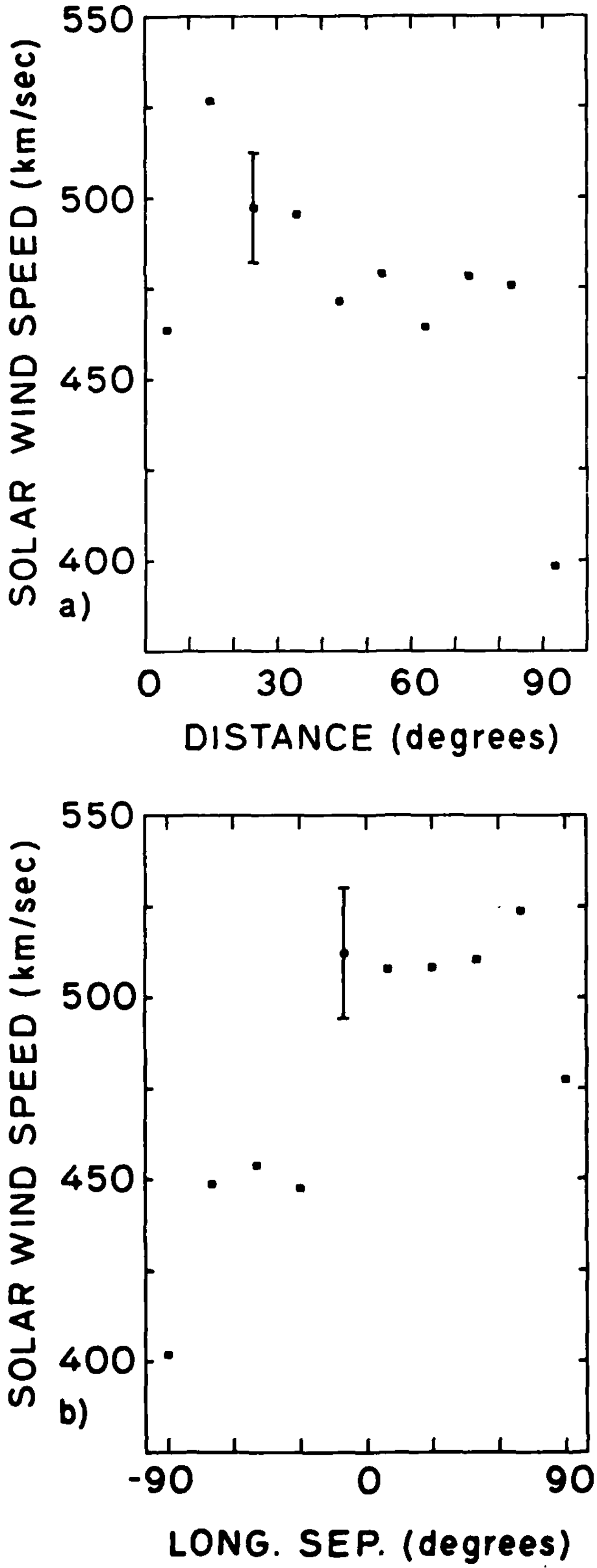

Fig.5. Plots of the average solar wind speed 2 to 3 days after a flare vs. a) angular distance from the subearth point and b) longitudinal seperation from the subearth point. Note the apparent strong east-west asymetry in b).

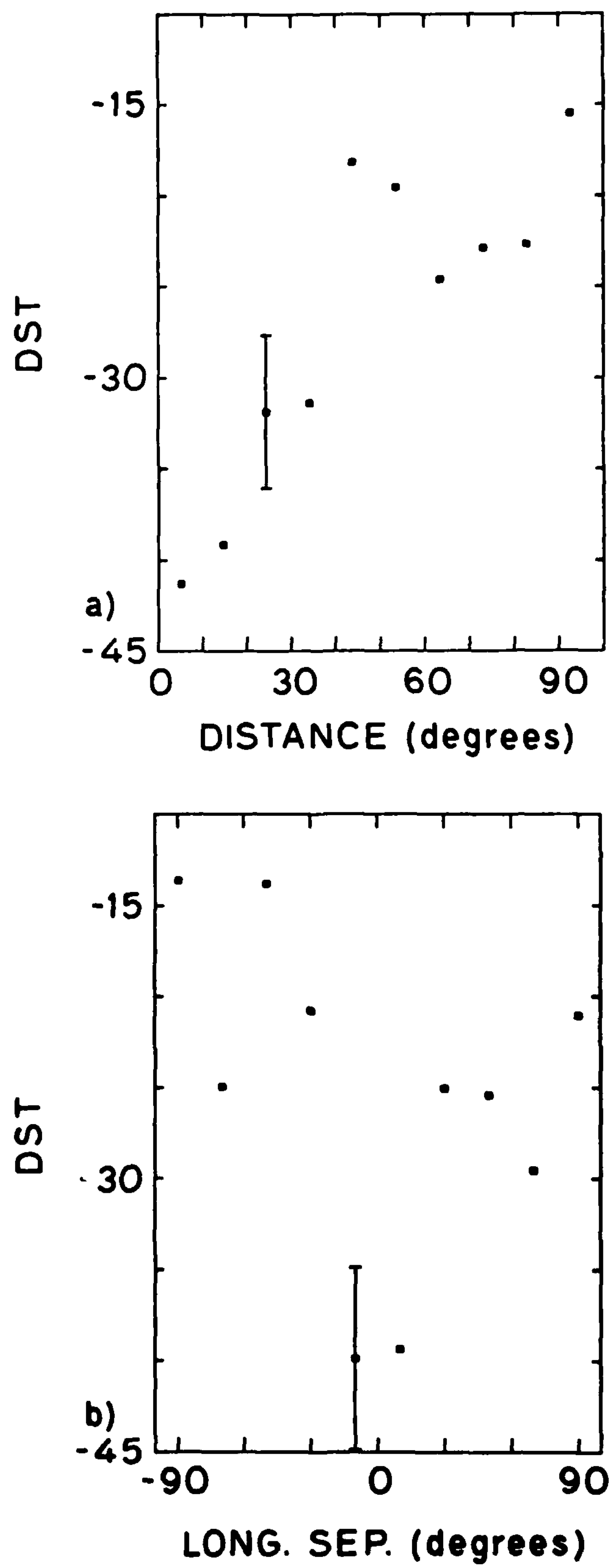

Fig.6. The same as figure 5, but for D_{ST} rather than solar wind speed. Note the lack of a strong east-west asymetry in b).

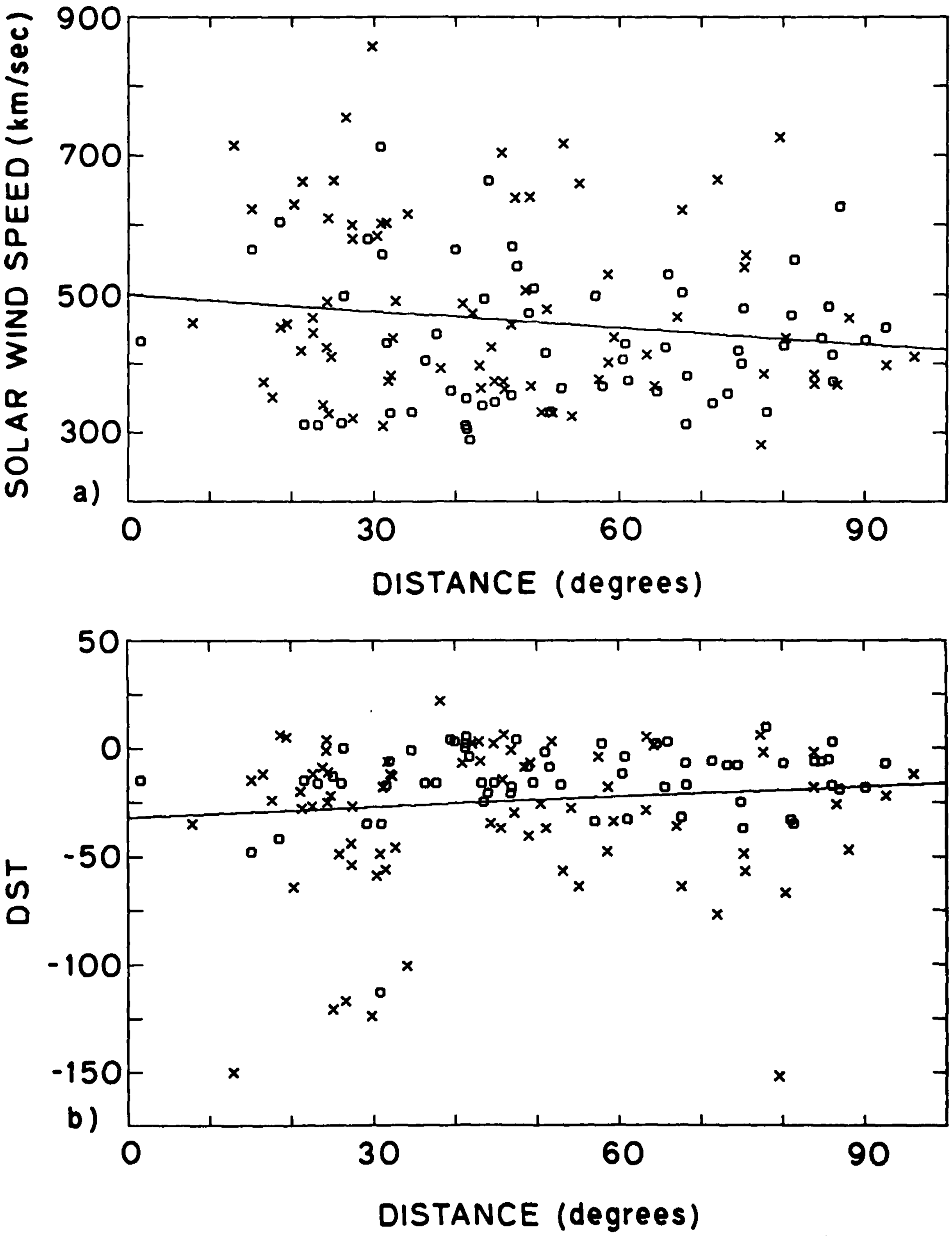

Fig.7. Graphs of a) solar wind speed and b) D_{ST} 2 to 3 days after a flare vs. angular distance. The line is a least squares fit to all points, and represents the effect of angular distance on the magnitude of the flare disturbance. Flares occuring on the opposite side of the HCS from Earth are marked with an *o*, those on the same side with an *x*.

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